FORAMINIFERAL DISTRIBUTION IN THE ESTUARINE GIPPSLAND LAKES SYSTEM, VICTORIA

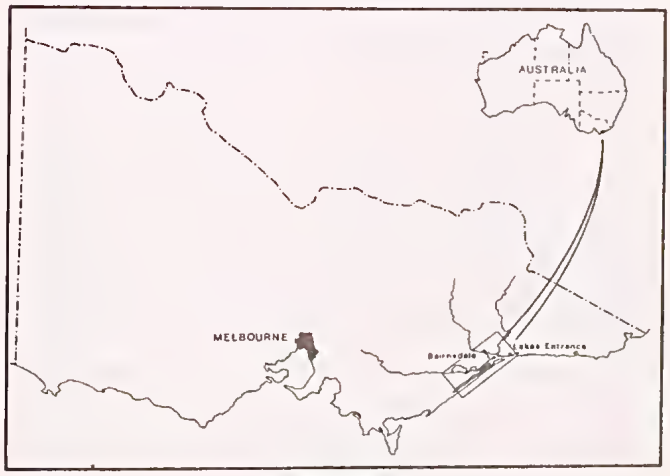
By M. Apthorpe*

Abstract: The estuarine system known as the Gippsland Lakes extends over 75 km along the coastal plain of eastern Victoria. A complete range of water salinities from almost fresh to marine is developed in the system. Variation in salinity appears to be the principal factor controlling the distribution of the eleven separate foraminiferal faunas developed in the bottom sediments. At the seaward end of the system a semi-marine, calcareous fauna is developed. Three separate central faunas occupy waters of intermediate salinity. Faunas at the landward extremes of the system are composed mainly of arenaceous foraminifera tolerant of very low salinities. Peripheral lagoons and channels contain variants of all these faunas, or occasionally distinctive assemblages of their own. Each assemblage is briefly described and an attempt is made to indicate controlling environmental factors. The pH of the substrate is also believed to be important in determining the major groups of foraminifera present. Below 6.5 only arenaceous types are present, while above 8.5 virtually only calcareous species occur. Between approximately 6.5 and 8.0, the two groups are mixed.

INTRODUCTION

The large estuarine system known as the Gippsland Lakes lies along the southeast coast of Victoria. The lakes are a string of connected shallow lagoons running subparallel to the coastline with Bass Strait, from which they are separated by a narrow dune ridge system, and swampy low sandy plains of variable width. The artificially dredged sea entrance, cut late in the nineteenth century, and just west of Lakes Entrance, maintains the estuarine character of these water bodies. Without this dredged channel, the lakes would return to a dominantly lacustrine system, with perhaps only occasional marine influence caused by storm breakthroughs in the dune barrier.

The lakes fill shallow depressions in an older coastal plain (Fig. 1) (see Bird 1965 for a detailed geomorphological study). They extend over a length of 75 km along the coastal plain. At its widest point the lakes system is approximately 16.6 km across, but has an average width of 5 to 8 km. It covers an area of approximately 280 km^2 but is generally less than 9 m in depth. The pronounced linear shape, as well as a subdivision into several lake basins with narrow connections, has the important effect of raising the number of discrete faunal associations occurring in a relatively small area. Freshwater influx into the lakes is provided by five major rivers (Fig. 1). Cool rainy winters produce a high stream discharge which lowers the salinity of the whole system in winter and spring. Warm dry summers generally mean that water loss by evaporation is largely replaced by seawater. During this period the entire lakes system is influenced by tides. The variation in water level is about 0.6 m at the seaward end, and appears to be somewhat less at the landward end in Lake Wellington. Although the salinity values change in response to the factors described above, at all times during the year, there is a salinity gradient. In water depths greater than about 1.6 m, there is a pronounced vertical salinity difference between bottom and surface water, due to the presence of a bottom wedge of denser more saline water. Because of their



Index Map

*Woodside Petroleum Development Pty. Ltd., Box D 188, G.P.O. Perth, Western Australia, 6001.

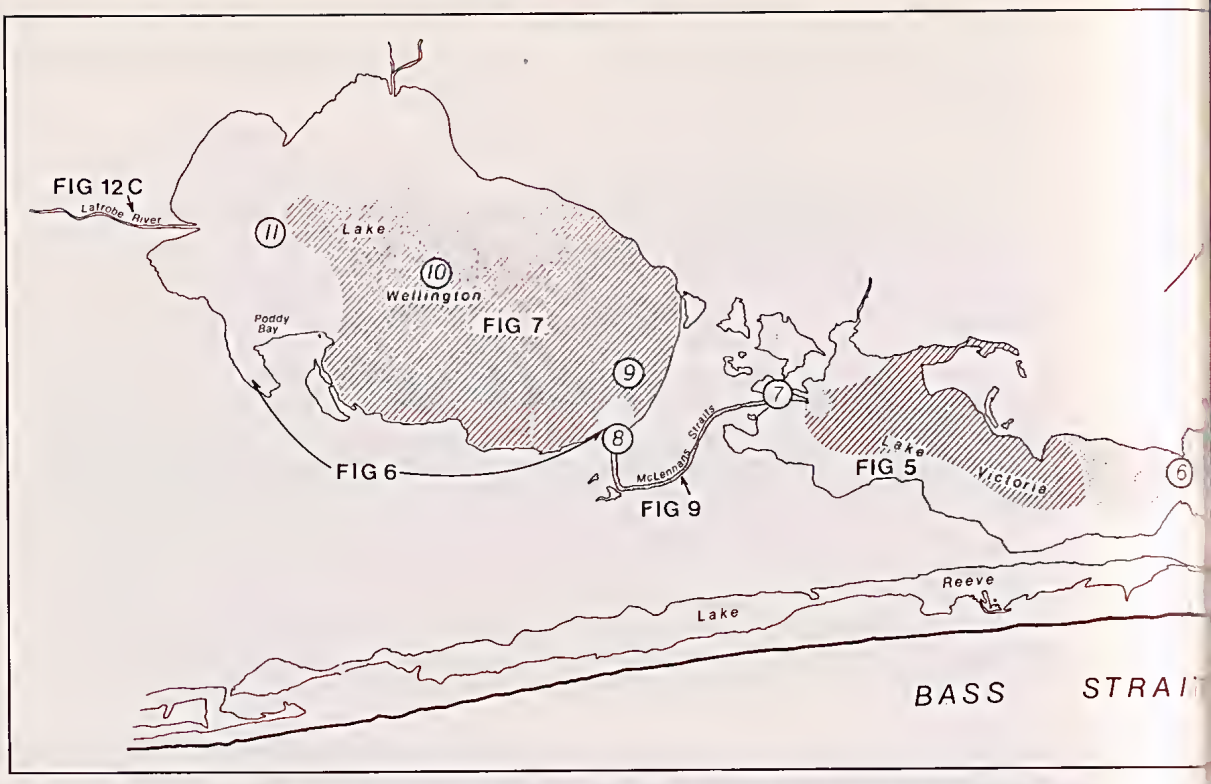


FIG. 1 — Key Map to Gippsland Lakes System, with index to faunas. Locations of subs detailed Figs. (2-12) are marked. These give details of different Faunas described

benthonic habitats, the foraminifera are influenced by the more saline bottom water.

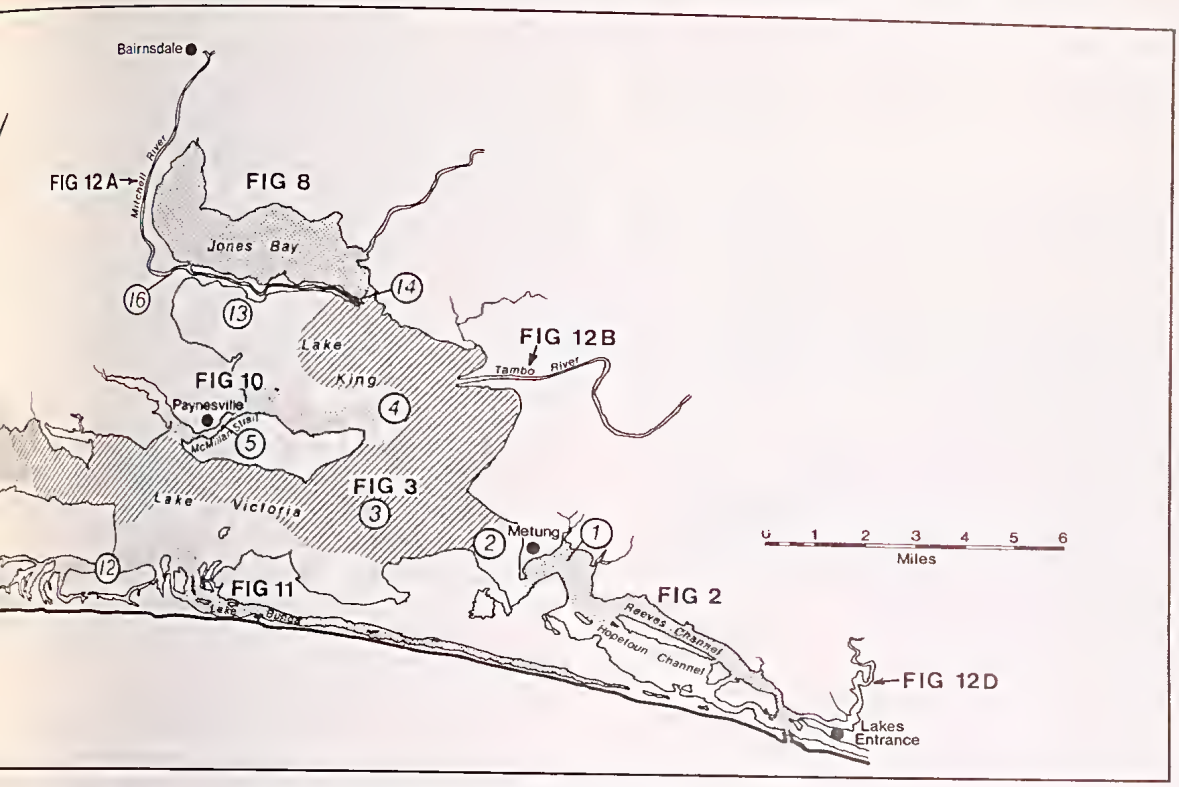
The central parts of all lakes are floored by clay or silty clay, often with a dense growth of vegetation. The colour of the clay varies from black in Lake Victoria to reddish tan in Lake Wellington. The margins of the lakes, and narrow waterways scoured by tidal currents, have medium to coarse-grained shelly sand bottoms. Shallow banks have patchy vegetation on a sand floor. Those areas of shallow protected lagoons less than a few metres deep are thickly carpeted with a filamentous algal growth.

Variations in substrate are caused by varying energy conditions. These are the result of 2 factors: (1) tidal currents, which move through narrow connecting channels with considerable velocity (enough to erode and transport silt-sized sediment), (2) waves, of up to 0.6 m high, caused by frequent and prolonged winds blowing parallel or subparallel to the long axis of the lakes system. This wave action is sufficient to sort sediment and produce a sandy sediment rim around the margins of most lakes. Shallow clay-floored lakes such as Wellington and Jones Bay appear to have part of their clay sediment in constant suspension. This constant turbidity of the water is tolerated by one species, *Martinotiella* cf. *communis*, which is most abundant in such areas. Different faunas are observed on sandy and muddy-floored portions of the same lake, where other environmental parameters appear to be similar.

The effect of pH values in bottom sediment on foraminiferal distribution was briefly examined and it appeared to be important in determining the major groups present.

PREVIOUS WORK AND BACKGROUND TO THE STUDY

The Victorian Ministry for Conservation has recently begun an intensive study of the Gippsland Lakes system, but at the time of this study, the only published work on the Lakes as an entity was that by Bird (1965). The present survey, the first on the foraminifera of the Gippsland Lakes, began as a modest private collection of samples taken for casual interest and without any overall study in view. The foraminiferal faunas of the early samples, when discussed with D. J. Taylor, were thought to be sufficiently interesting to continue the collection of material. The aim of the survey has been to determine the qualitative and quantitative compositions of the foraminiferal faunas, and to suggest, if possible, some reasons for the distribution patterns of different taxa



Encircled numerals 1-16 indicate Water Sampling Stations of Victorian State Rivers Water Supply Commission.

and faunas. It is hoped that such a survey will provide a starting point for more detailed investigations.

The only local foraminiferal study with which the Gippsland results could be compared was that by Collins (1974) on the foraminifera of Port Phillip Bay at Melbourne. Port Phillip is a single body of water, very much larger than the Gippsland Lakes, and is overall of more marine character. Collins's study was of the nature of a faunal inventory. An examination of Collins's material in the collection of the National Museum of Victoria showed little, if any, similarity between the assemblages of the two areas.

SAMPLING EQUIPMENT AND METHODS

Sampling was carried out over a four-year period from 1970 to 1973, usually late December to early January, and in April, when circumstances permitted. Samples were collected using a simple dredge dragged behind a boat. It collected sediment to a depth of 3 cm over a linear path of about twenty m. Water samples were collected using a heavily weighted bottle, or were taken direct from the sediment water mixture in the dredge in shallow water areas. Water salinity measurements were carried out by the Victorian Department of Minerals and Energy, Chemical Branch. The monthly salinity readings taken by the Victorian State Rivers and Water Supply Commission (hereafter referred to as "State Rivers") at 16 stations were also utilized for those months in which samples were collected. Readings for pH were taken using indicator papers made by the British Drug Houses Company. Some readings were confirmed by Department of Minerals and Energy measurements.

In the laboratory, a 20g sample of sediment was washed free of clay-sized particles, dried, and floated in carbon tetrachloride to separate the foraminifera. The foraminifera in all 366 samples collected were then identified and counted. Because of the method of collection and the consequent mixing of surface and subsurface material, it was impossible to separate foraminifera living on top of the sediment from those living or dead within the top layers of sediment. Selective staining of some samples with Rose Bengal to identify live specimens showed that the living species did not differ greatly in composition from the dead specimens in the same samples. Because of this it is considered that the total fauna present in each sample gives a fair representation of the living population at each site. Post-mortem transportation of specimens, with the exception of tidal channels, is believed to be minimal.

A collection of foraminiferal preparations,

consisting of part or all of the foraminifera recovered from each 20g sample, are stored in the Department of Invertebrates, National Museum of Victoria, Melbourne. A list of sample locations is lodged with the samples.

The discussion of the foraminiferal faunas encompasses all the samples examined, but only selected 'typical' samples have been shown in graphical form on the Figures. Distribution tables, either in abbreviated form showing selected samples only, or in complete form giving all samples and all species identified, are available on request from either the author or the Royal Society of Victoria.

FORAMINIFERAL ASSEMBLAGES

At least eleven benthonic faunal assemblages have been distinguished in the lakes during this survey. Because of the small number of species and the constant character of most assemblages, simple 'pie diagrams' have been used on Figs. 2-12 to illustrate the foraminiferal distribution. The faunas are fairly distinct, with little overlap at any one time, but resampling of some sites indicates that the faunal assemblages may migrate in response to varying environmental conditions. Some samples may represent mixing of two distinct faunal assemblages which were deposited in very thin layers in the lake sediments.

In common with hyposaline lagoons and estuaries in other parts of the world the foraminifera belong almost entirely to two suborders, *Textulariina* and *Rotaliina* (Murray 1973). The third suborder, the *Miliolina*, occurs only in the semi-marine entrance to the lakes system. Also in common with other lagoonal and estuarine systems, the species diversity is generally low in the lake faunas, and fairly high in the marine-influenced entrance fauna.

Planktonic foraminiferal species are virtually absent. In Fauna 1 (nearest the sea) five samples contain 1.5% planktonic species, but none at all were found in other faunas.

The faunal assemblages are listed below. For Fauna 1-8 the principal distinguishing forms are given.

Marine Faunas, Bass Strait.
Fauna 1 — Semi-Marine Fauna: with Miliolids.
Fauna 2 — Central Lakes Fauna: *Ammonia/Eggerella*.
Fauna 3 — Central Lakes Fauna: *Ammonia/Eggerella/Nonion*.
Fauna 4 — Southern Lake Victoria Fauna: *Ammonia/Elphidium oceanensis*.
Fauna 5A — Inner Lakes: arenaceous: *Trochamminita*.
Fauna 5B — Inner Lakes: mixed arenaceous/calcareous: *Martinotiella/Miliammina/Ammonia*.
Fauna 5C — Inner Lakes: mainly arenaceous: *Martinotiella/Miliammina/Ammobaculites/Ammonia*.
Fauna 6A — High Energy Channels — McLennans Strait: *Ammonia/Ammotium*.
Fauna 6B — High Energy Channels — McMillan Strait: *Eggerella/Ammobaculites/Miliammina*.
Fauna 7A — Low Energy Environments — Lake Bunga: *Ammobaculites*.
Fauna 7B — Low Energy Environments — Lake Bunga: *Elphidium*.
Fauna 7C — Low Energy Environments — Lake Reeve: *Elphidium articulatum/Ammonia*.
Fauna 8 — River Faunas.

The *Marine Faunas* of Bass Strait were sampled at only three stations immediately outside the entrance to the lakes. Sparse faunas were found in sands of the turbulent nearshore zone. They are not discussed here, as an analysis of them is beyond the scope of this paper. The major assemblages of the Gippsland Lakes system are as follows:

Fauna 1 — Semi-Marine Fauna

This occurs in the deep Reeves Channel connecting the main lakes with the sea at Lakes Entrance. The relatively straight channel runs for 10 km along the base of the Pleistocene coastal escarpment from Metung to Lakes Entrance (see Fig. 2). The channel is about 400 m wide for most of its length, 10-12 m deep in the centre, carries most of the water exchanged between lakes and ocean and has the highest current velocity (tidally induced) of any part of the lakes system under normal (i.e. nonflood) conditions. Sediment samples recovered in the channel are of silt or silty sand. Related faunas occur in the shallow Hopetoun Channel to the south, but these will be discussed separately.

The principal feature which distinguishes this foraminiferal fauna from all others in the lakes is the presence of miliolids. This group is predominant in many shallow water marine environments, including the immediately adjacent area of Bass Strait. At the seaward end of Fauna 1, the miliolids form over half the total population. The second feature which distinguishes this fauna is the high species diversity of over 20 species per sample with the maximum number recorded being 58 in sample GL 145. High diversity is one feature which distinguishes marine assemblages from lacustrine or marginal marine assemblages. Abundance is variable, depending on the nature of the sediment. Sandy samples contain under 100 specimens, whereas finer grained samples contain thousands per 20g of sediment.

Approximately 10 different species of miliolid foraminifera are present, the most common being

Quinqueloculina seminulum, *Q. tropicalis*, *Miliolinella subrotunda* and *Triloculina trigonula*. Species belonging to the Family *Elphidiidae* are common in all samples. *Elphidium macellum* is important in the north-east half of the area of Fauna 1, while *E. advena*, *E. articulatum* and *Cribroelphidium poeyanum* are more common with increasing distance from the sea. Moving up Reeves Channel towards the lakes, *Ammonia aoteanus* becomes the dominant species, forming 30% to 70% of the total population in the inland half of this fauna. Calcareous foraminifera are completely dominant over arenaceous types. The genus *Cibicides*, which is abundant or dominant in many shallow marine shelf assemblages, is almost completely absent from this fauna. Among the minor species present *Textularia pseudogramen* is a species living on the Gippsland continental shelf which is found only in the seaward end of Fauna 1. *Eggerella advena*, which is characteristic of Lake Victoria faunas, occurs in abundance in some samples towards the lakesward end of Fauna 1. *Trochammina rotaliformis* seems to occur only in samples where tidal currents sweep around promontaries or through narrow channels. This species is prominent in sample 204 (in Rigby Strait, discussed later); in sample 242 between Pelican Island and Barwon Point; in sample 5 (strictly in Fauna 2) where strong currents pass the shore at Metung; and it occurs in small numbers in central Reeves Channel. *Fursenkoina fusiformis* and *Nonion depressulum* occur in very small numbers in the lakeward part of the area of Fauna 1. Another 60 species occur in very small numbers scattered along the length of the Reeves Channel without apparent pattern. These include *Ammobaculites barwonensis*, *Haplophragmoides canariensis*, *Martinotiella cf. communis*, *Miliammina fusca*, *Reophax barwonensis*, *Trochammina inflata*, *Quinqueloculina* cf. *ferrusacci*, *Q. striata*, *Triloculina tricarinata*, *Angulogerina angulosa*, *Anomalina glabrata*, *Astrononion tasmaniensis*, *Bolivina pseudoplicata*, *B. striatula*, *B. variabilis*, *Bolivinella folium*, *Bulimina gibba*, *B. marginata*, *Buliminella elegantissima*, *Cassidulina cf. neocarinata*, *C. subglobosa*, *Cibicides refulgens*, *C. mediocris*, *Conorboides advena*, *Discorbinella subberiheloti*, *Discorbis* spp., *Euuvigerina peregrina*, *Fissurina annectens*, *Guttulina problema*, *G. regina*, *Lagena* spp., *Lenticulina* spp., *Patellinella inconspicua*, *Pileolina patelliformis* and *Planodiscorbis rarescens*. A small number of planktonic specimens, mainly juveniles, occur in most samples.

This fauna occurs in salinities of 30 to 35‰. Readings at State Rivers Station No. 1, in Reeves Channel east of Metung were somewhat lower, ranging from 26 to 30.4‰. For months in which samples were taken, the readings for this station were:

		Salinity (‰)
January	1970	28.7
March	1970	26.6
January	1971	25.9
April	1971	30.0
April	1972	30.4
June	1972	27.18
December	1972	28.4
April	1973	29.58

Water sample 138 (collected at the end of December 1970) near the seaward end of the area had a salinity of 35.4‰. Two samples (144, 145) taken immediately afterwards 7 km further inland along the channel, where *Ammonia* was the most abundant foraminiferid, had water salinities of 25.8 and 30.1‰. The difference in these last two adjacent samples reflects the presence of a wedge of denser, more saline water at depth, overlain by a lighter less saline surface layer. In June 1972 a water sample (no. 280) at the same location as sample 243 gave a salinity of 30.5‰.

The semi-marine Fauna 1 does not occur in a second broad channel to the southeast (the Hopetoun Channel) which also connects the main lakes and the sea (see Fig. 2). Although wide, most of the area is extremely shallow and covered with dense weed beds. A central channel, some 2 to 2.7 m deep, winds to the sea entrance and is floored with mixtures of sand, silt and clay. Water flow through this shallow channel system appears to be only a fraction of that in Reeves Channel. Samples from this area have salinity values of 26, 29 (two samples) and 31‰. The proximity of this area to Reeves Channel invites comparison of the faunas. In the Hopetoun Channel, faunas are very variable. The nature of the substrate appears to be an important control here. The faunas in the sandy channels are dominated by *Ammonia aoteanus* with fewer *Elphidium* spp. and other species. Miliolids are absent (with the exception of a single sample — 252). The number of species per sample is lower than in Reeves Channel faunas.

Two samples (246, 247) were taken in Yellow Bay, a protected backwater at the southwestern end of the Hopetoun Channel. The water depth here is 4 m, but 2 m of this is occupied by a dense growth of filamentous algae. Sample 246 from a small patch of black silty clay within the weed beds produced abundant molluscs and a foraminiferal assemblage dominated by *Ammobaculites barwonensis* (63%), with *Ammonia aoteanus* (27%) and *Elphidium articulatum* (3.8%). Sample 247 was barren. The weed bed fauna of sample 131, taken in the main channel off Kelly Head in less than 2 m of water, was entirely different, consisting largely of algae with only a few grams of

LEGEND

123• Sample No. with location well defined

(67) Sample No. with location vague

NF No foraminifera found

ANF Almost no foraminifera found

Approximate limits of fauna

TEXTULARIINA

Ammobaculites barwonensis

Ammotium salsum

Eggerella advena

Martinotiella communis

Miliammina fusca

R Reophax barwonensis

Trochammina rotaliformis

Trochamminita irregularis

MILIOLINA

ROTALIINA

Ammonia aoteanus

Cribroelphidium poeyanum

Elphidium articulatum

E Elphidium macellum

Elphidium oceanensis

Nonion depressulum

TO BE USED IN CONJUNCTION WITH FIGS. 2-12.

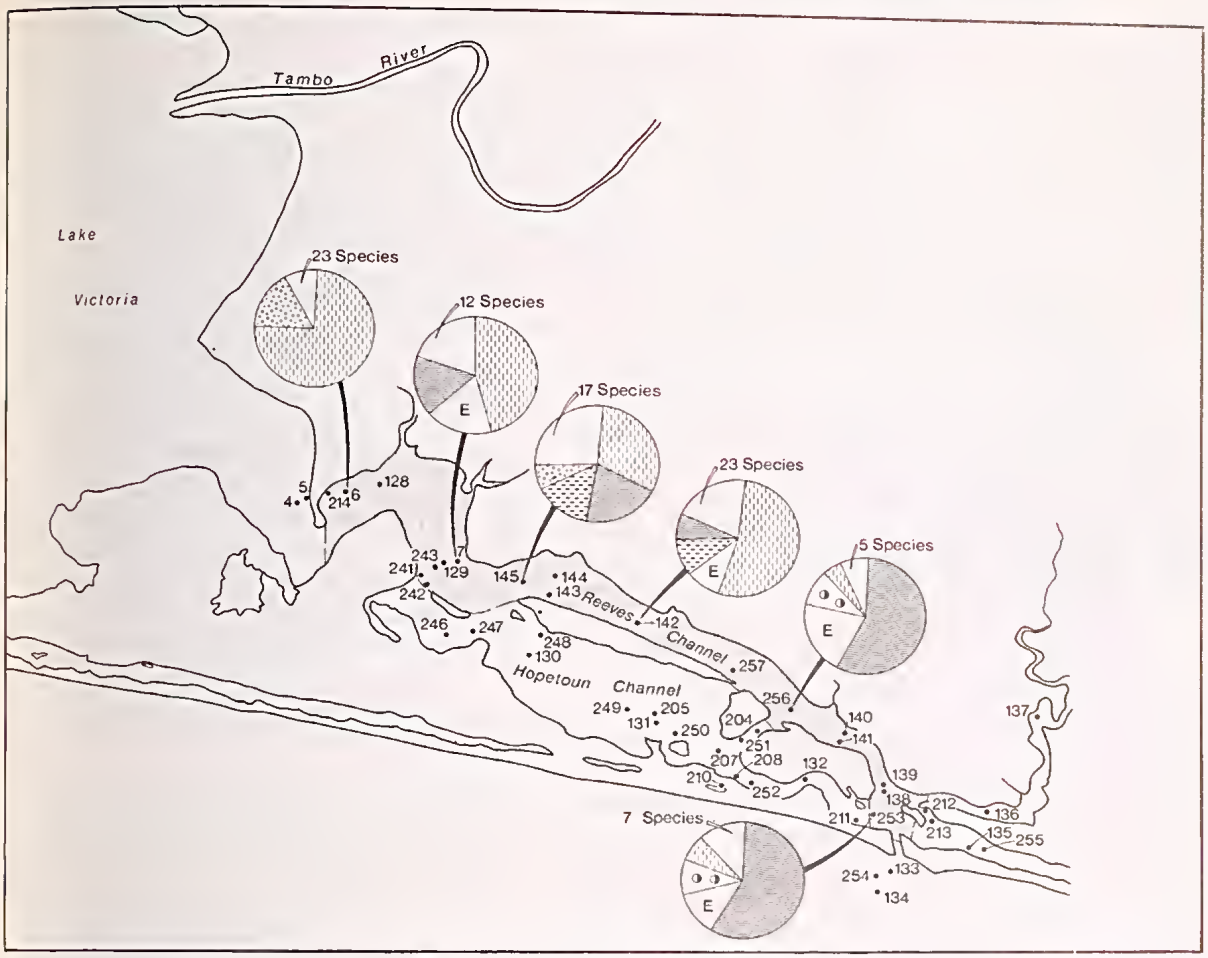


FIG. 2 — Fauna 1: Semi-marine Fauna.

black clay adhering to the plants. Very abundant small gastropods and ostracods, all living, were recovered from the algal fronds. Abundant living *Miliammina fusca* made up 95% of the foraminiferal assemblage, and it is believed that most of the specimens were recovered from the algae rather than from the clay of the substrate. Both these faunas suggest that arenaceous species predominate in weed-covered areas of the lakes regardless of salinity and other factors.

Another faunal variant in this area is the high percentage of *Trochammina rotaliformis* in the sparse faunas on shallow sand banks (sample 248: 77%; sample 250: 76% *T. rotaliformis*). The species is less common in the faunas of channels in this area (sample 130: 10%, sample 204: 6%; sample 251: 4.5%). In summary, on the sand banks *T. rotaliformis* is dominant, with minor *Ammonia aoteanus* and *Miliammina fusca*, whereas in the channel faunas *Trochammina rotaliformis* is overshadowed by *Ammonia aoteanus* and *Elphidium articulatum*.

Four samples were taken in the Cunninghame Arm, east of Lakes Entrance township. The sparse faunas in samples 135, 212, 213 and 255 are very similar to those of the Hopetoun Channel. *Ammonia aoteanus* is the most common species, with minor numbers of *Elphidium articulatum*, *Elphidium macellum* and *Cribroelphidium poeyanum*. Numerous other species occur in extremely small numbers.

Fauna 2 — CENTRAL LAKES FAUNA

Lake Victoria and its western extension, Lake King, are the principal water bodies of the Gippsland Lakes, being 38 km long, and 7-10 m deep over much of their area. Fauna 2 occupies the seaward parts of these lakes and is one of the most extensive faunas in the lake system (see Fig. 3). It appears to be partially controlled by substrate, having been found only in clay or very fine silt in the central, deeper parts of the lakes.

Fauna 2 is composed almost entirely of only two species — *Ammonia aoteanus* and *Eggerella advena* in roughly equal numbers. It has the lowest diversity and greatest abundance of any fauna, which is surprising considering its proximity to the entrance to the lakes. Four of the samples collected in 1970 had

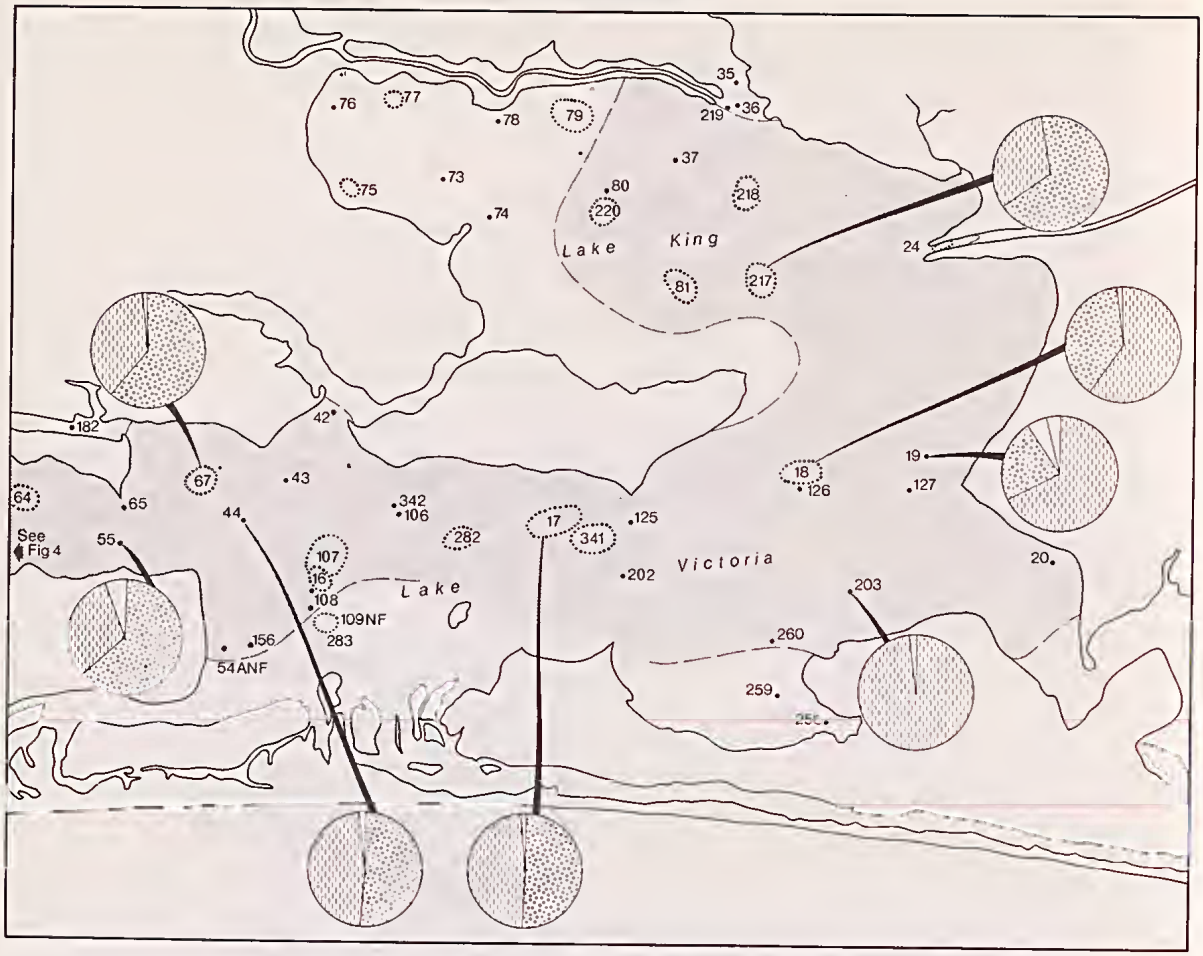


FIG. 3 — Fauna 2: Central Lakes Fauna (*Ammonia/Eggerella*).

over 10,000 specimens per 20g of sediment. Later samples did not approach these numbers, but most had over 1,000 specimens per 20g. Only two pH readings (of 7.0 and 7.5) were taken in Lake King during sampling.

Water salinity values were mostly in the range of 26 to 31‰. However, considerably lower salinity measurements, of 12, 15 and 20‰, were obtained in this area at different times during 1970. The samples associated with the readings of 12 and 20‰ were almost totally lacking in foraminifera. The samples of 15‰ had very high population numbers, so that no coherent picture emerges on the salinity range for this fauna. In general, *Eggerella advena* comprises more than half the population in the lower salinity samples from the inland part of this fauna (samples 217, 17, 107, 43, 44, 67, 55, 64). *Ammonia aoteanus* forms more than half the population in the more seaward samples of this fauna (samples 6, 4, 20, 19, 18, 125, 126). *Ammonia aoteanus* is a world-wide hyposaline species capable of withstanding considerable variations in salinity. In the Gippsland Lakes it occurs in salinities down to 5‰ and probably below this value. However, the enormous population numbers in this fauna, coupled with a large specimen size, may suggest that the salinities between 15 and 31‰ represent an optimum for the species. The largest specimens of *Ammonia aoteanus* are 1 mm across, very thick walled, and with thickened raised sutures. Juvenile specimens are also abundant. Less than 1% of the populations from the central lake basins were made up of the species *Bulimina marginata*, *Fursenkoina fusiformis* and *Bolivina* spp. Small numbers of other species near the margins of this fauna reflect transitions to adjacent faunas.

This fauna was more frequently sampled than most, and it was possible to detect some changes in time. In January and March 1970, *Eggerella advena* generally equalled or outnumbered *Ammonia aoteanus* and these were virtually the only species present. In January 1971, one year later, *Ammonia* greatly outnumbered *Eggerella* and buliminids were a minor component. The change to a 'more marine' fauna corresponded with a rise in salinity, from 15.3‰ in

January 1970 to 26.4‰ in January 1971 (Figures from State Rivers Sample Station No. 3).

A variety of assemblages occur around the edge of Fauna 2 which do not fit into any defined fauna. Faunas on the shallow sandy lake margins are usually sparse. Most are dominated by *Ammonia aoteanus* with *Miliammina fusca* and/or *Ammobaculites barwonensis* (e.g. in Purran Corner — samples 259 and 260). Faunas in the northwest corner of Lake King (samples 73-79) are sparse but varied mixtures of *Ammonia aoteanus, Eggerella advena, Ammobaculites barwonensis, Martinotiella* cf. *communis* and *Cribroelphidium poeyanum. Ammonia aoteanus* is the most abundant species, but the samples have little else in common. The area requires more detailed sampling. Off the mouth of the Mitchell River, three samples (35, 36, 219) contain a mixture of faunas. Sample 219 contains a fairly typical Fauna 2. Samples 35 and 36 have a high content of *Miliammina fusca* and other arenaceous species and appear to be influenced by the faunas of Jones Bay and by the discharge of the Mitchell River.

Fauna 3 — Central Lakes Fauna with *Nonion depressulum*

Occurring in the central portion of Lake Victoria, this fauna, as the name implies, is a modification of the Central Lakes *Ammonia-Eggerella* assemblage just discussed. Like that fauna, it is confined to the low energy muddy central areas of the lake.

As with Fauna 2 diversity is notably low and *Nonion depressulum* joins *Ammonia aoteanus* and *Eggerella advena* as the only important components. Either *Ammonia* or *Nonion* may be the most abundant species, varying from sample to sample. The percentage of *Eggerella* drops steadily throughout the area of Fauna 3 away from the boundary of Fauna 2. Proceeding from northeast to southwest the percentage of *Eggerella* decline as follows (see Figs. 4 and 5 for locations):

Sample No.	% *Eggerella advena*
64	59
57	23
63	37
59	20.4
60	20.5
62	13
123	2
110	9.5
173	4.7
111	13.5

Eggerella advena is rare in Fauna 4, to the southwest, and is not seen further from the sea than the southwest end of Lake Victoria.

Other species which occur in very small numbers in more than one sample are: *Textularia* sp., *Cribroelphidium poeyanum, Elphidium articulatum, Elphidium oceanensis* and *Virgulinella fragilis*. Total numbers of foraminifera in samples attributed to this fauna are low, with almost all totals below 1,000.

Salinity readings from State River Station 6 (which is located roughly near sample 63) during months of collection ranged between 23 and 28‰. Two water samples from shallower areas adjacent to the fauna, gave readings of 16.2 and 22.1‰. The overall impression of this fauna is that it is a fringe variant of Fauna 2, probably reflecting slightly lower salinities.

Marginal faunas from the sandy, wave-agitated edges of this area differ from those of the central lake area, where the substrate is of black clay. *Nonion depressulum* is reduced in numbers, or absent, in the higher energy conditions. *Miliammina fusca*, which is absent in the low energy central lake samples, is important in the higher energy marginal samples.

Fauna 4 — Southern Lake Victoria

This poorly characterised fauna at the southwestern end of Lake Victoria contains very few specimens and is included here only because it appears to cover a fairly large area (see Fig. 5). This fauna is dominated by *Ammonia aoteanus*, with a fairly wide variety of other calcareous and arenaceous species. *Elphidium oceanensis* occurs in most samples but is not seen elsewhere in the lakes. Calcareous species include *Cribroelphidium poeyanum*, and occasional *Nonion depressulum*. Arenaceous species include *Miliammina fusca, Eggerella advena, Ammotium salsum, Martinotiella* cf. *communis*, and *Trochammina inflata*. These arenaceous species reflect the influence of adjacent McLennans Straits (*Ammotium* fauna) and Lake Wellington beyond (Fauna 5).

No sample contains more than 1,000 specimens per 20g, and most contain fewer than 300. Samples in the southeastern half of the lake (numbers 238, 119, 174) are barren and several others are almost barren. The area has not been sampled in sufficient detail to define precisely the areal extent of the fauna, or to detect nearshore variations. No data on salinity was collected for this area. Presumably it is generally intermediate between the values of the northern end of McLennans Straits (17-22‰) and those of the central part of Lake Victoria (23-28‰).

Fauna 5 — Inner Lakes

The inner lakes faunas are composed of euryhaline species which tolerate the lowered and fluctuating salinities due to river discharge at the most inland parts of the lakes system. Of the three recognisable faunas two are entirely arenaceous, and one is a mixed calcareous/arenaceous assemblage.

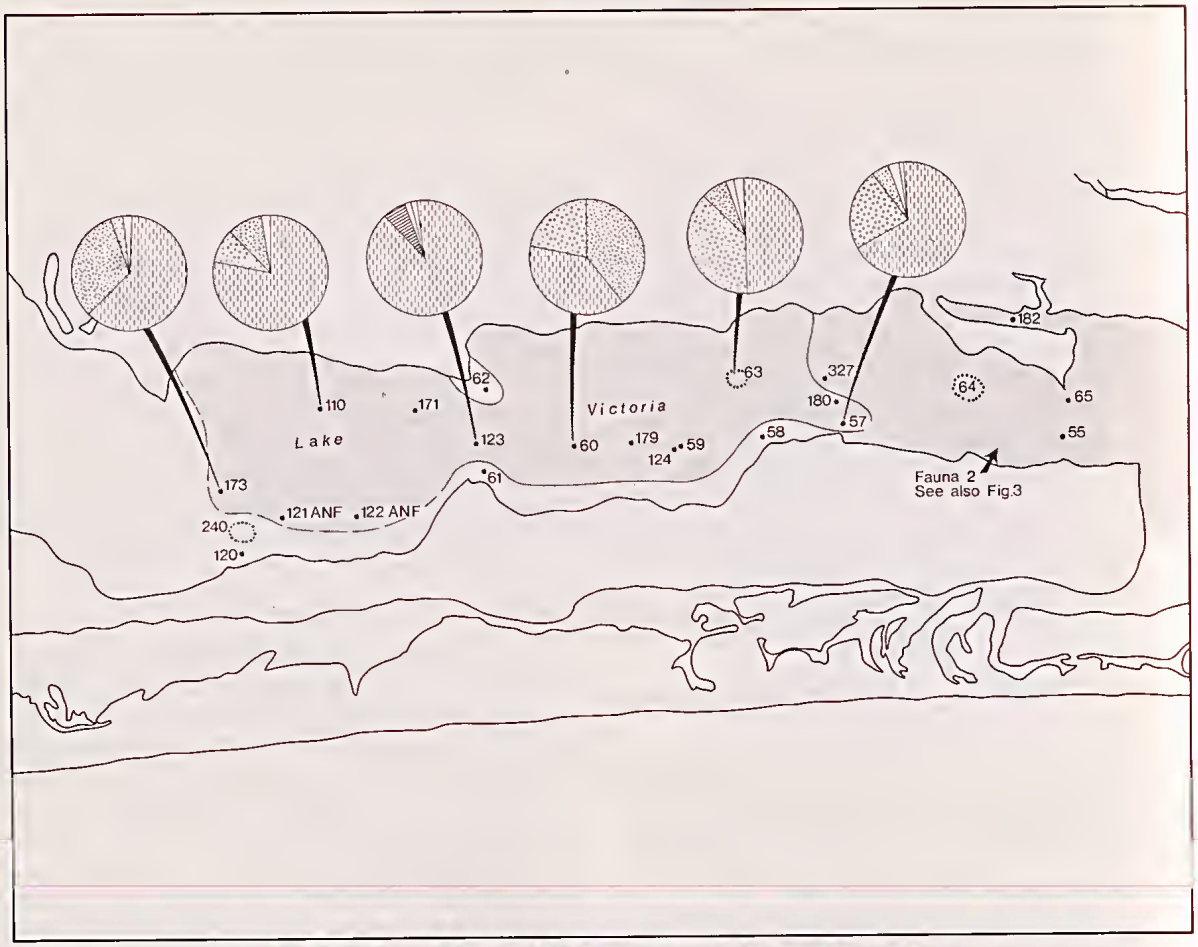


FIG. 4 — Fauna 3: Central Lakes Fauna with *Nonion depressulum*.

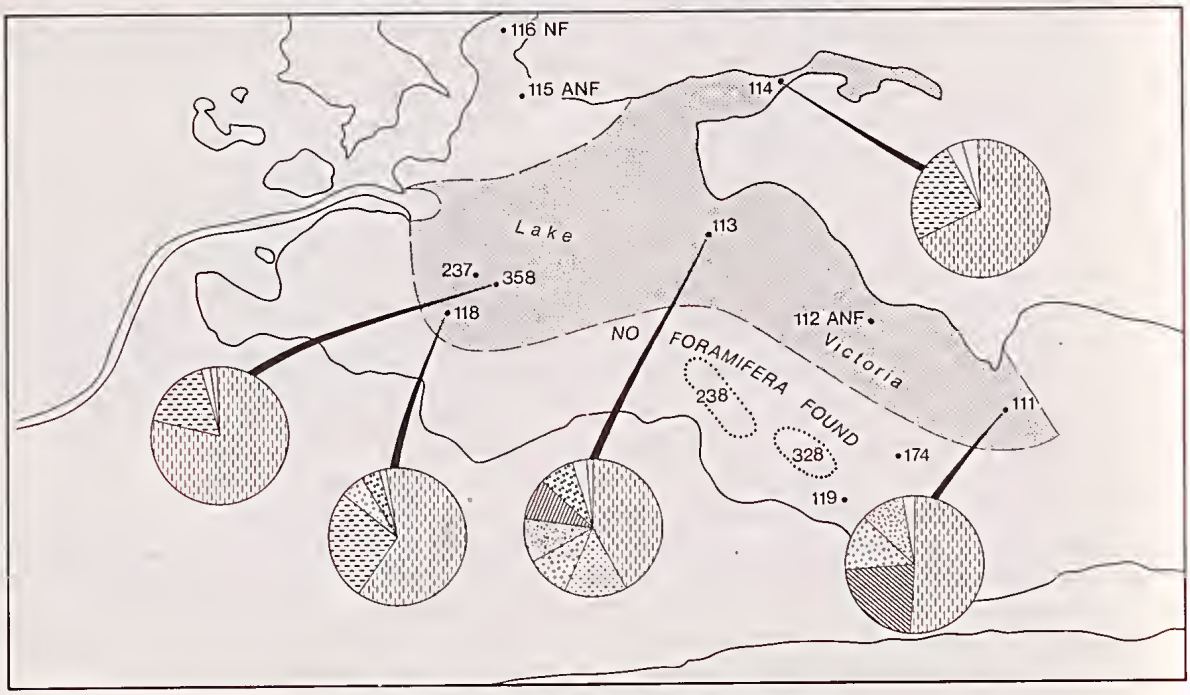


FIG. 5 — Fauna 4: Southern Lake Victoria Fauna.

Fauna 5A — Arenaceous: *Trochamminita*

At the time of this survey, it was confined to small areas in Lake Wellington, namely, a bay on the south side (Poddy Bay), and an area adjacent to the entrance channel (McLennans Straits) (see Fig. 6). Both areas are in shallow water (0.6-1.6 m), with a bottom of sand mixed with minor black mud. Current action and water circulation are active at the latter site. Fresh water from the adjacent Latrobe River probably has a considerable influence on Poddy Bay.

Fauna 5A is the 'least marine' of all the faunas encountered in this survey. It consists of 40% to 78% of *Trochamminita irregularis*. The remainder of the fauna is composed of *Milliammina fusca* and *Ammotium salsum*, with minor *Reophax barwonensis*, *Martinotiella* cf. *communis* and *Trochammina inflata*. Some of the specimens of *Miliammina fusca* and *Trochamminita irregularis* occur as aberrant forms with greatly extended or irregular terminal chambers. The organic internal linings of *Ammonia aoteanus* are also present in one sample. The occurrence of these linings is discussed in connection with Fauna 5B.

No salinity readings from Poddy Bay were available. At the nearest State Rivers water sampling station in Lake Wellington (Station 11), salinities ranged from 0.35 to 5.5‰ at a time when typical faunas of this group were collected in Poddy Bay. Values at the entrance to McLennans Straits (the second area of Fauna 5A) in 0.5 m of water were probably a little above the surface water reading of 0.6‰ for this location (State Rivers Station 8 — April 1971). These salinity values from areas adjacent to Fauna 5A suggest that the fauna flourishes in water that is only slightly brackish.

The pH of 6.0 measured for Fauna 5A in Poddy Bay was one of the lowest recorded during the survey. This appears to be the important factor excluding the calcareous tests of *Ammonia aoteanus*, which is capable of tolerating low salinities. The presence of organic inner chamber linings from *A. aoteanus* in sample 232 indicates that the species moved into the area and that complete dissolution of the calcium carbonate shell wall took place. It seems unlikely that this species could survive for any period, or reproduce, under these

FIG. 6 — Fauna 5A: Inner Lakes Arenaceous Fauna.

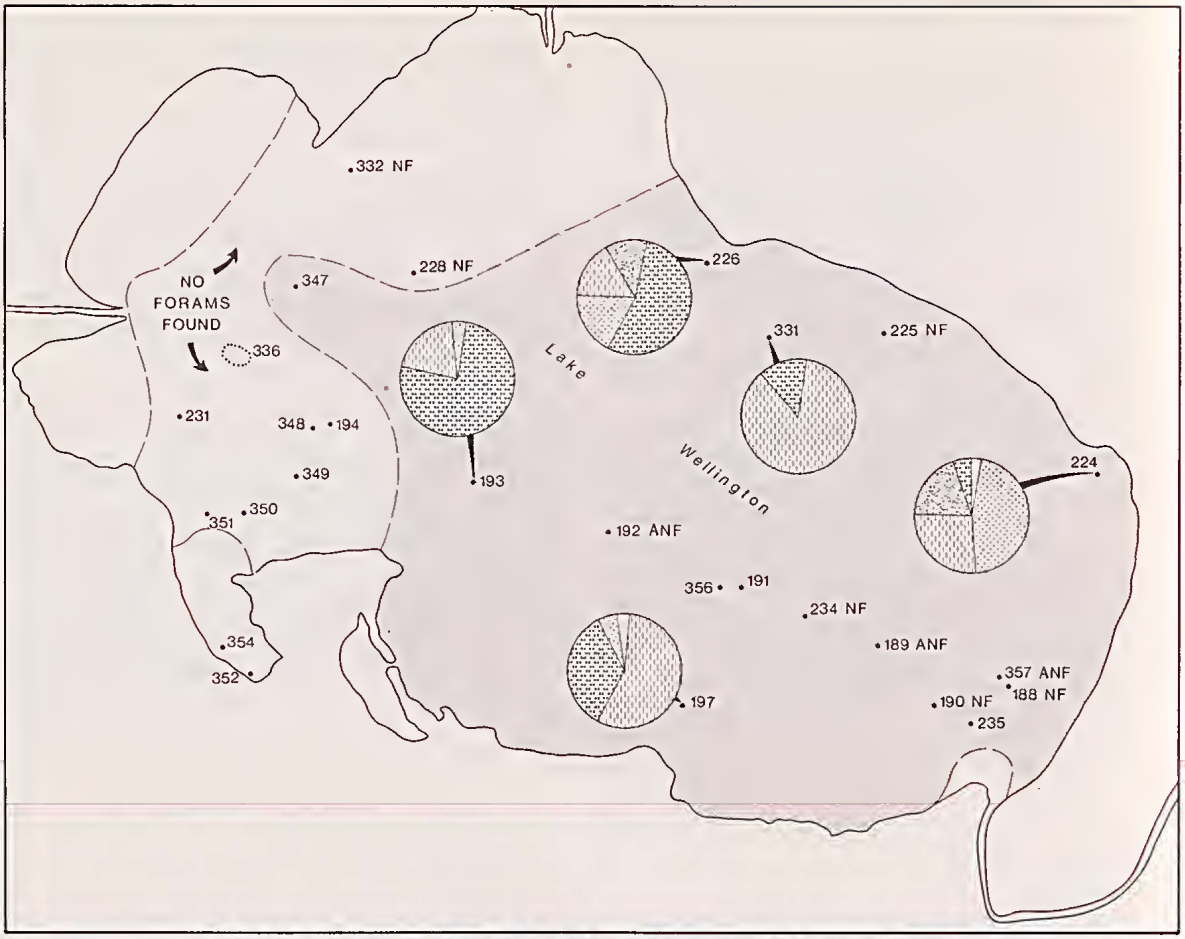


FIG. 7 — Fauna 5B: Inner Lakes Mixed Arenaceous/Calcareous Fauna.

conditions. A pH value of 6.0 or below in the substrate is therefore believed to cause the entirely arenaceous foraminiferal fauna.

Fauna 5B: Mixed Arenaceous/Calcareous: *Martinotiella/Miliammina/Ammonia*

Lake Wellington is the most inland of the lakes, a shallow (1-2 m deep), almost enclosed body of water 16 km long and 8 km wide (see Fig. 7). Due to shallowness, wind-induced waves keep the clay sediment constantly in suspension. The sediments are tan to reddish clays, occasionally interbedded with black clays similar to those of the more seaward lakes. Some areas on the northern and eastern shores have a rim of sandy sediment. The western and southern shores of the lake were not visited.

Fauna 5B which occupies the eastern two thirds of Lake Wellington, is composed principally of the arenaceous species *Martinotiella* cf. *communis*, *Miliammina fusca*, *Ammotium salsum*, and the ubiquitous calcareous species *Ammonia aoteanus*. The dominant species varies from sample to sample. Very minor components include *Trochamminita irregularis*, *Cribroelphidium poeyanum* and *Elphidium oceanensis*.

The abundance of specimens is generally moderate to low, usually below 500 in number. Many of the samples collected in central Lake Wellington did not contain foraminifera, nor did the ten samples from the western (inland) end of the lake (see Fig. 7).

The salinity varied from a low of 7.3‰ to a high of 12.4‰. Readings from State Rivers Stations 9, 10 and 11 during sampling months are variable. They range from a low of 0.35‰ at Station 10 (in the centre of the lake) in April 1971, to a high of 17.4‰ at Station 9 (near the McLennans Straits entrance) in April 1973. In general, Station 9 had higher salinities, and the deeper water probably contributed to the more pronounced difference between surface and bottom water salinities. At Stations 10 and 11 in the centre and the western end of the lake, the surface and bottom water salinities were close to each other, probably due to mixing by waves. Most of the bottom water

salinities during sampling months fell between 5 and 12 parts per thousand.

Several pH readings of 6.5 were obtained from samples of this fauna. Significantly, specimens of *Ammonia aoteanus* are extremely thin walled and lacking in calcareous ornament. Many specimens have their calcareous tests partially or wholly dissolved, leaving only the brown organic chamber lining in the sediment (Pl. 29, figs. 1, 2) similar to those illustrated by Quilty (1977). It seems that a pH of between 6.0 and 6.5 represents an environmental cut-off point for the survival of the species. It can survive at 6.5, but it is not known whether the species would reproduce at this pH value. Repeated migration of juveniles from Lake Victoria in strong tidal currents is a possible mechanism for the maintenance of the population numbers.

Fauna 5C: Mainly Arenaceous: *Martinotiella/Miliammina/Ammobaculites/Ammonia*

This fauna occupies the northern extension of Lake King, an area known as Jones Bay. Like Lake Wellington, this almost closed body of water has two major rivers contributing fresh water to it, and also like Lake Wellington, it is shallow (1-2 m), muddy, and constantly stirred by wind-induced waves. The fauna is similar to that of Lake Wellington, being largely arenaceous, but this area is inhabited by more species. *Martinotiella* cf. *comunnis* (common in Lake Wellington) is the most important form here, making up 22% to 79% of faunas. Other abundant arenaceous species include *Miliammina fusca*, *Ammobaculites barwonensis*, *Ammotium salsum*, and rare *Eggerella advena*, *Trochammina inflata*, and *Trochamminita irregularis*. Calcareous species include small percentages of *Ammonia aoteanus*, and rare *Cribroelphidium poeyanum*. The number of specimens varies from under 50 to as many as 2200 and 4800 in two samples located directly outside the two entrances to the Mitchell River. This probably reflects a higher concentration of nutrients brought in by the river.

The only salinity reading available is 9.5‰ in a sample just outside the upper entrance to the Mitchell River. It seems probable that the average salinity further down the bay towards Lake King would be a little higher than this. The only pH value known for the area occupied by the fauna is a reading of 4.2 in sample 28, the same sample as the salinity reading above. The predominance of arenaceous forms suggests that a value of 6.5 or below is likely over most of this area. Of particular interest is the presence of sheet-like bryozoa in sample 30 (see Fig. 8; Pl. 29, fig. 15), in a turbid brackish environment.

Fauna 6 — High Energy Channels

These comprise two connecting channels between lakes, each with considerable tidal current flow. Their faunas are predominantly or wholly arenaceous, but composed of different species.

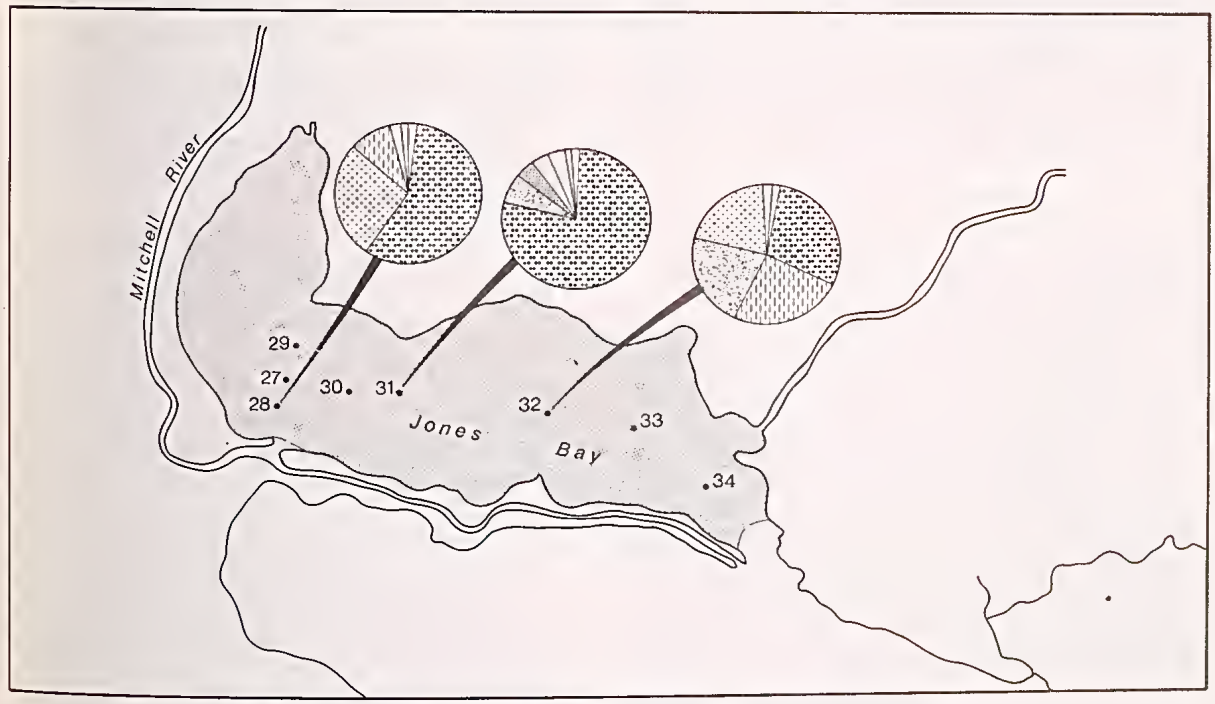


Fig. 8 — Fauna 5C: Inner Lakes Dominantly Arenaceous Fauna.

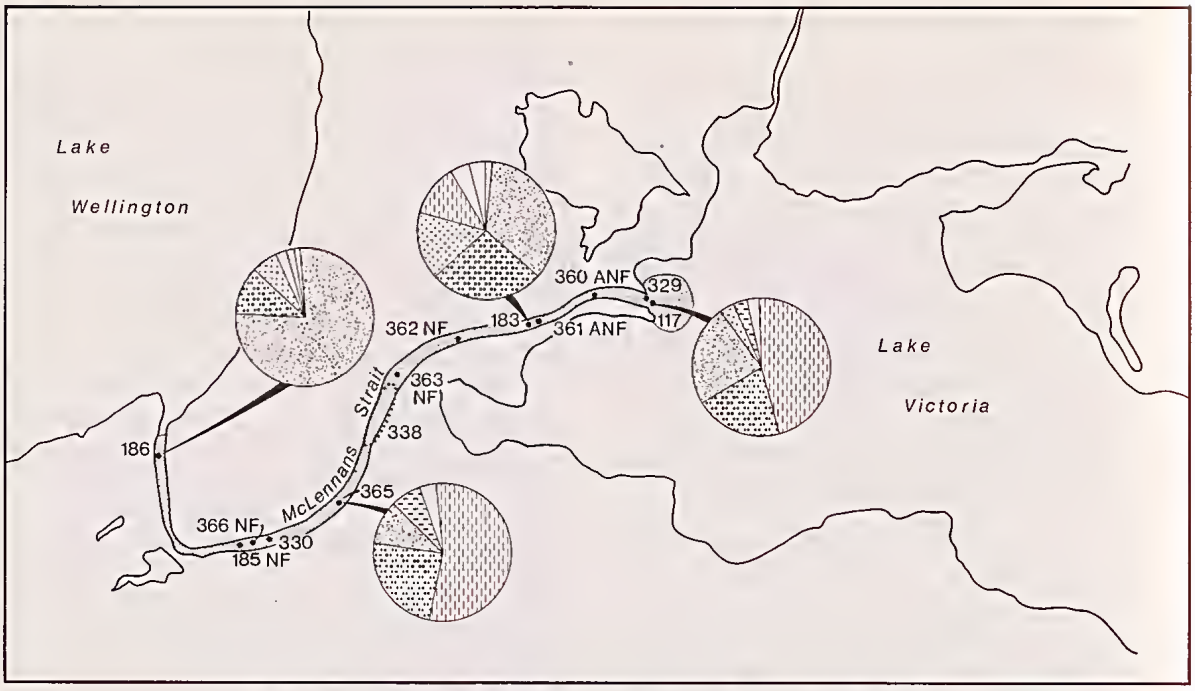


FIG. 9 — Fauna 6A: High Energy Channels: McLennans Strait.

Fauna 6A: McLennans Strait: *Ammonia/ Ammotium*

McLennans Strait is a narrow steep-sided channel up to 10 m deep cutting through low swampy land between Lake Wellington and Lake Victoria (see Fig. 9). The channel floor appears to be scoured bare in many places. Many tows of the dredge brought up no sediment, and repeated efforts brought up only very small samples of silt and sand. Salinity figures are given from State Rivers Station 7 at Hollands Landing (sample location no. 360 — see Fig. 9).

Date		Salinity ‰ (Bottom Water Readings)
January	1970	4.46
March	1970	15.00
January	1971	2.72
April	1971	20.20
April	1972	19.50
December	1972	17.50
April	1973	22.24

The figures (for months in which samples were collected) range from 2.7‰ to 22.2‰, with the higher figures in April. The figure for December 1972 (17.5‰) differs considerably from that of sample no. 338 (26.9‰), which was collected in the same month. The figures emphasize the considerable salinity variations to be expected in the channel connecting the two largest lakes in the system.

The numbers of foraminifera in this channel were low, a maximum of 327 being recovered from any one sample. Half the samples were barren, or almost barren. The fauna is dominated by *Ammonia aoteanus*, but with important numbers of *Ammotium salsum* and *Martinotiella* cf. *communis*. The abundance of *Ammotium salsum* distinguishes the fauna from that of Lake Wellington to the west, where *A. salsum* is occasionally present, and from the Lake Victoria faunas, from which it is almost absent. Other species in the McLennans Strait fauna include *Miliammina fusca, Cribroelphidium poeyanum, Trochammina inflata, Trochamminita irregularis, Haplophragmoides canariensis* and *Elphidium oceanensis*.

Fauna 6B: McMillan Strait: *Eggerella/ Ammobaculites/Miliammina*

McMillan Strait, connecting parts of Lake King and Lake Victoria, is a relatively short channel with a strong tidal flow and floor of black silt and sand. The faunas comprise about 90% arenaceous species. *Eggerella advena*, one of the dominant forms of the adjacent central lakes fauna (Fauna 2) is the most abundant species. Others are *Miliammina fusca, Trochammina inflata, Martinotiella* cf. *communis*, and *Ammobaculites barwonensis*. *Ammonia aoteanus* is unsually sparse (less than 10% in all samples). The salinity is a little lower than that of the adjacent central lakes. Two readings of 19.4 and 22‰ were recorded at State Rivers Station 5 during sampling months (March 1970, April 1971). The high velocity and san-

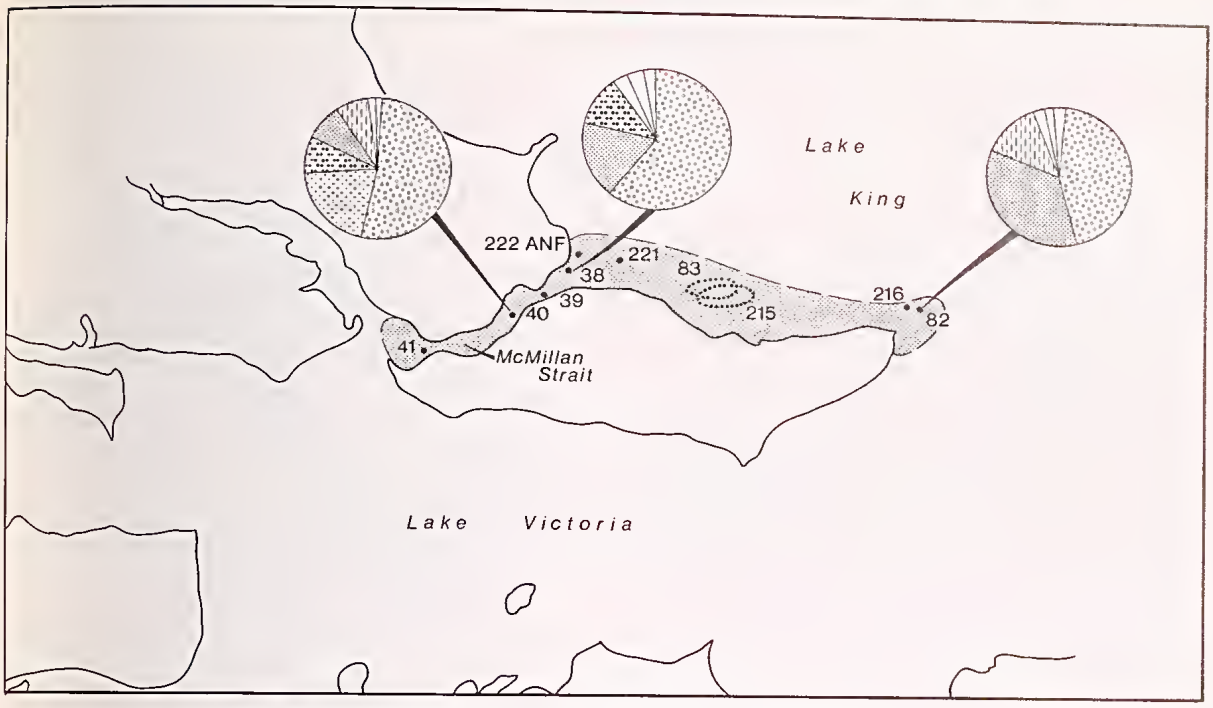


FIG. 10 — Fauna 6B: High Energy Channels: McMillan Strait.

dier substrate may also be important environmental differences.

This fauna also extends out into Lake King, particularly along the northern side of Raymond Island. The sandy substrate is the only known difference between this area and the central part of Lake King.

Fauna 7 — LOW ENERGY ENVIRONMENTS

The peripheral Lakes Bunga and Reeve are long narrow bodies of water separated from Bass Strait by a coastal strip of sand dunes. Although under tidal influence, they are out of the main water circulation pattern of the lakes. These lakes support two distinct microfaunas, one calcareous and one arenaceous. It is suspected that light penetration and water depth, salinity and substrate, may all control the distribution of these faunas within each lake.

Fauna 7A: Lake Bunga: *Ammobaculites*

Lake Bunga, the larger lake, is 15.4 km long and less than 270 m wide, 4.5-6.0 m deep, and floored by black mud overlain by a dense cover of filamentous algae. Over most of the lake, for the entire four-year period of the study, *Ammobaculites barwonensis* was the dominant, and sometimes the only foraminifer present. The other principal component was *Reophax barwonensis*. Minor species occasionally present were *Miliammina fusca, Martinotiella* cf. *communis* and *Ammobaculites agglutinans*. For this fauna, the only salinity value known is one of 17.4‰.

Fauna 7B: Lake Bunga: *Elphidium*

At the northeastern end of Lake Bunga, variation in the environment results in a completely different fauna. Much higher salinities of 27 to 31.6‰ were encountered, probably due to evaporation. The water was extremely shallow (0.3-0.9 m), and the bottom was composed of silt or sand, largely free of weed cover. The fauna was composed of *Criboelphidium poeyanum* and *Elphidium articulatum*. Green algae are conspicuous in the chambers of the foraminifera. This fauna is associated with shallow areas of high light penetration.

The same fauna was also found living in extreme environmental conditions in small, shallow (less than 0.3 m depth) pools connected to Lake Bunga, at Bunga Head (see Fig. 11 — samples 322 to 325). The salinity in these pools was 40‰ and a saline crust was forming on exposed mud flats at the edge of the pools. The water temperature was 28°C, the pH of the water 8.0, and the pH of the mud surface 9.5. Despite the fine-grained, gelatinous nature of the sediment forming, the pools were clear due to their small size and protected location. The fauna was composed almost entirely of *Elphidium articulatum*, with transitional forms resembling *Cribroelphidium poeyanum*. It seems possible that the whole population represented a single, rather variable species, and not two separate genera as implied by the taxonomy. In four samples over 60% of the specimens were living when collected. The fauna demonstrates the high tolerance to variations

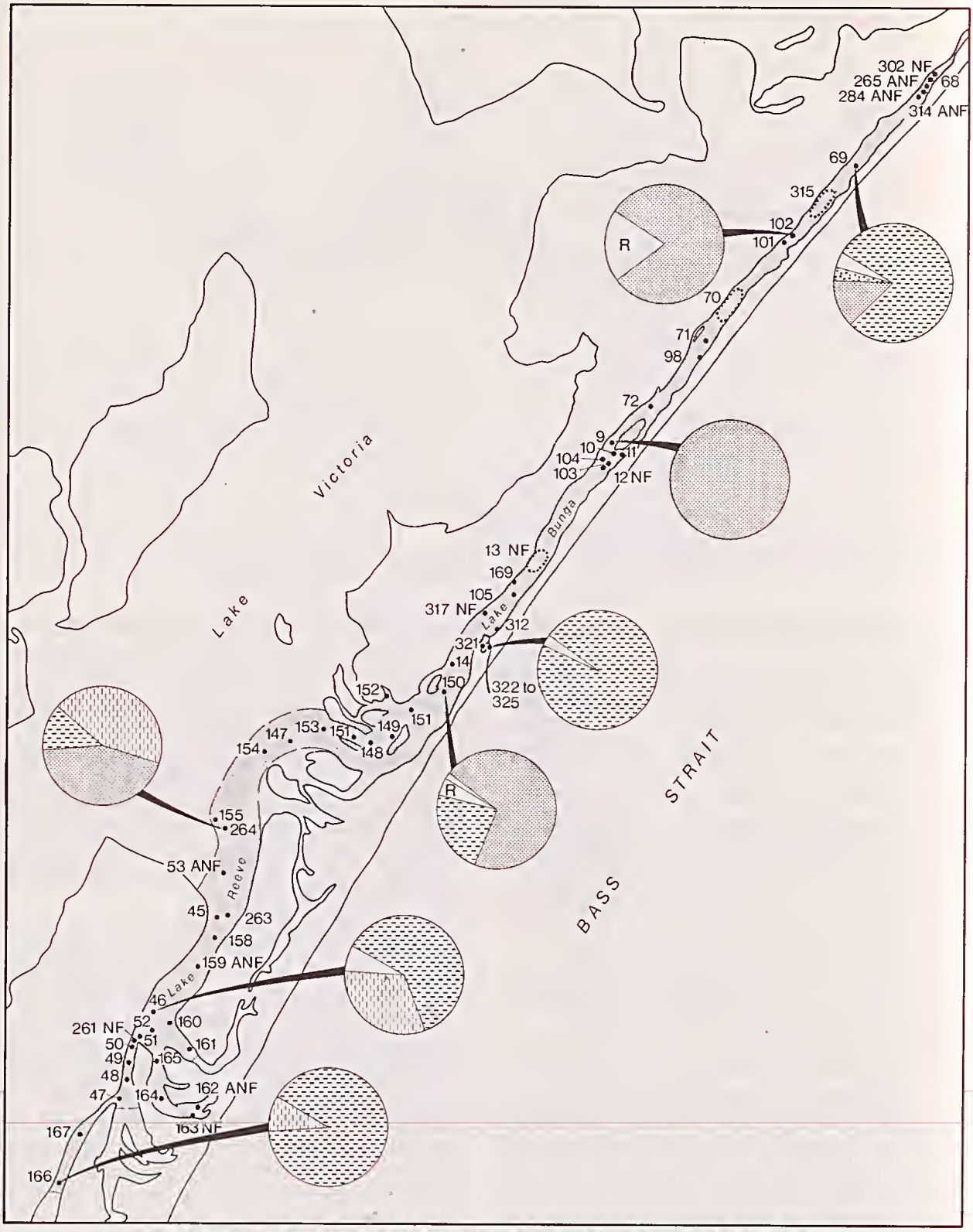


FIG. 11 — Fauna 7A, 7B and 7C: Peripheral Lakes: Lake Bunga and Lake Reeve.

in salinity characteristic of the unkeeled *Elphidium* group (Murray 1973).

Fauna 7C: Lake Reeve: *Elphidium articulatum/Ammonia*

Lake Reeve, although an extensive depression, is largely a string of salt marshes which are dry for much of the year. The water-filled northern end of the lake is less than 1 m deep over most of its area. This end of the lake is broken up into small arms and bays by the complex form of the Pleistocene dune barrier system (see Figs. 1 and 11). The bottom sediment varies from black clay with extremely dense weed beds, to a few areas of shelly sand. The lake is so shallow that little wave motion is generated, since the mats of vegetation almost everywhere reach the water surface. Small depressions between the weed banks provide clear water, undisturbed areas in which faunas of *Elphidium articulatum*, *Cribroelphidium poeyanum* and some *Ammonia aoteanus* are present. In the deeper water area adjacent to the entrance of Lake Reeve, the faunas contain a considerable number of *Ammobaculites barwonensis*, which may have spread from Lake Bunga. Four salinity readings available from samples are 15.3‰, 18.9‰, 22.7‰ and 30.9‰.

Fauna 8 — River Faunas

The lower parts of three rivers and one creek flowing into the Gippsland Lakes were sampled (see Fig. 12). With the exception of the delta of the Mitchell River, the foraminiferal faunas are extremely sparse. Three samples from the Latrobe River channel were barren. All samples from the Mitchell River above its junction with Jones Bay were barren, or virtually so. The Mitchell River delta channel contained a sparse fauna dominated by *Ammobaculites barwonensis* in the upper part. *Ammonia aoteanus* was present in sample 96, nearer the mouth, where the faunal numbers rose slightly. In the Tambo River also, sample 21, furthest upstream, was dominated by *Ammobaculites barwonensis*, while downstream *Ammonia aoteanus*

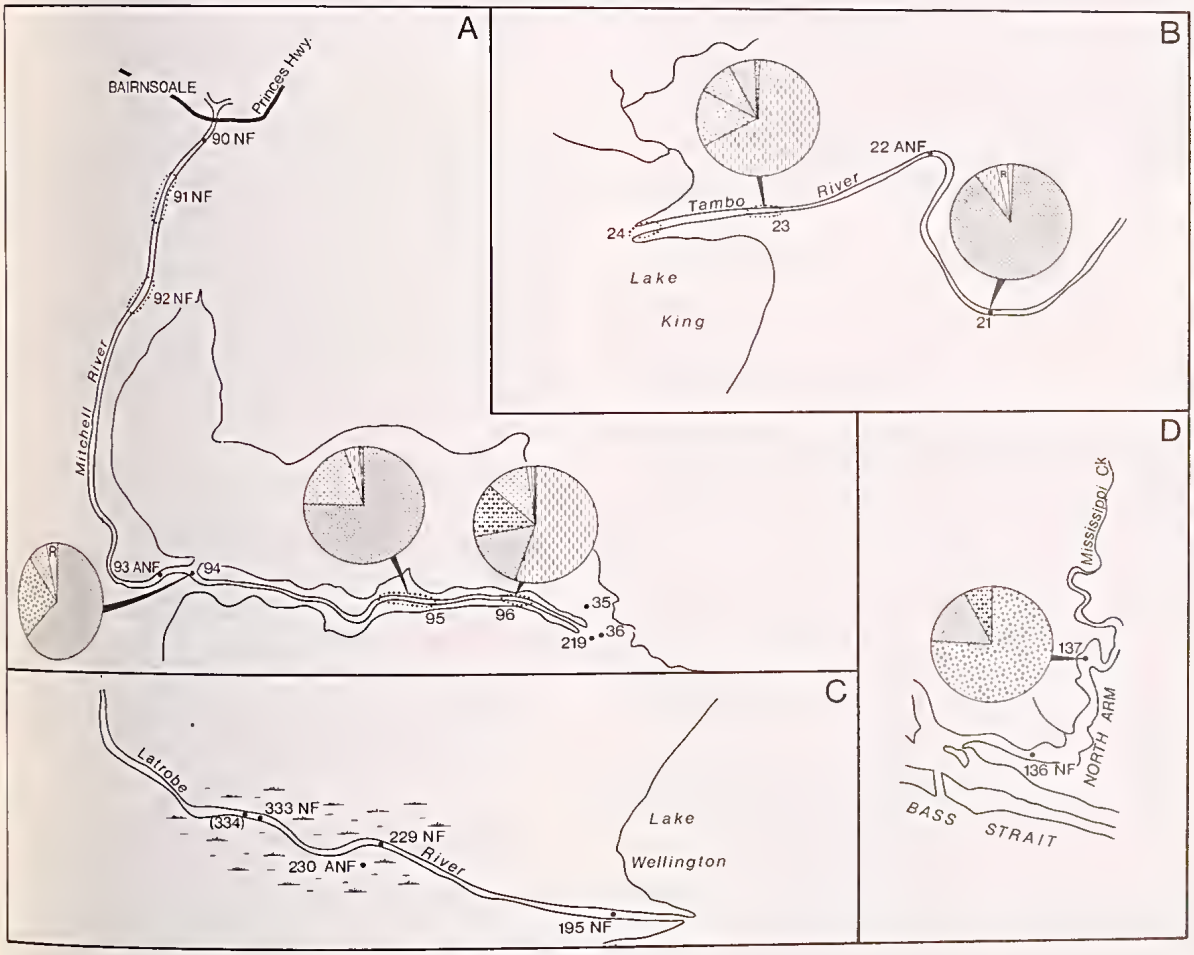


Fig. 12 — River Faunas.

became dominant in the sparse fauna. The only abundant fauna found was at the mouth of the river, where the fauna is transitional to that of the central lakes, Fauna 2.

A single sample from the tidal creek known as the North Arm, north of Lakes Entrance, yielded a small wholly arenaceous fauna. Here *Eggerella advena* was dominant, with *Ammobaculites barwonensis* next in importance. The rivers were not sampled in sufficient detail to draw any conclusions as to the effect of salinity changes on the foraminifera.

It is believed that the lower parts of virtually all the rivers are brackish at times, due to a salt water wedge. This view is based on the salinity figures for the Latrobe, which is the furthest inland of the sampled streams. The absence of foraminifera from the lower part of the Latrobe (and from western Lake Wellington beyond) remains unexplained.

CONCLUSIONS

Despite the preliminary nature of this survey, and the need for future detailed studies, some observations on the foraminiferal faunas and their environment as developed in the Gippsland Lakes can be suggested.

1) Salinity appears to be the most important single factor controlling the faunal assemblage of an area. The salinity ranges of some important faunas, so far as they can be gauged from the sparse data, are:

		Salinity, ‰
Seaward	Fauna 1	20-35
↑	Fauna 2	(12) 15-31
	Fauna 3	16-28
	Fauna 6A	3-22 (27)
↓	Fauna 5B	0.3-12 (17)
Inland	Fauna 5A	0.3-5?

The values in parenthesis ( ) are believed to be atypical.

2) The pH of the substrate appears to be important in determining whether wholly arenaceous, wholly calcareous, or mixed faunas occur. Some tentative observations:

Above pH 8.5	— generally wholly calcareous faunas (*Elphidium*)
7.0-7.5	— mixed arenaceous and calcareous faunas.
6.5	— mixed faunas, but with calcareous tests thin walled and showing dissolution effects.
6.0 and below	— either wholly arenaceous faunas, or faunas with small numbers of calcareous species (*Ammonia*) showing severe dissolution effects.

3) The type of substrate in the Gippsland Lakes appears to depend on the energy level produced by the action of waves and tidal currents. The nature of the substrate — whether sand, clay or weed — appears to be of some importance in determining which one of several species, having similar salinity preferences, will be present. It has been pointed out in discussion of Faunas 2 and 3 that there are differences between the faunas of the central clay and weed-floored lakes, and the faunas of the sandy turbulent nearshore areas. Some of these contrasts between nearby samples are illustrated below:

Area	Sample No.	Substrate	Main foraminifera (in order of abundance)
Lake Victoria (Fauna 2)	81	Clay	*Ammonia aoteanus* *Eggerella advena* *Nonion depressulum*
	82	Sand	*Eggerella advena* *Ammobaculites barwonensis* *Ammonia aoteanus*
Lake Victoria (Fauna 3)	60	Clay	*Nonion depressulum* *Ammonia aoteanus* *Eggerella advena*
	61	Sand	*Miliammina fusca* *Ammonia aoteanus* *Cribroelphidium poeyanum* *Eggerella advena*

Arenaceous species are associated with dense weed beds, or with areas of turbidity. *Miliammina fusca* and *Ammobaculites barwonensis* were found living in abundance in weed beds, and *Martinotiella* cf. *communis* was common in areas of shallow, turbid clay sediments. *Eggerella advena* reaches its maximum numbers in clay substrates, but is also found in sands. Despite its occurrence in weed beds as noted above, *Miliammina fusca* was also found consistently in sandy substrates. *Elphidium* spp. were abundant in sandy nearshore areas.

4) High and low energy environment: a tendency for *Ammotium salsum* and *Trochammina rotaliformis* to be common in areas of current activity has been noted.

5) Variations within this shallow lake system are so small that depth is not, in itself, a factor influencing the faunas. However, variations in depth have a profound influence on whether the lake floor is within reach of the effect of waves. This factor in turn dictates the type of substrate, which to some extent influences the type of foraminifera present.

TAXONOMIC NOTES

Brief notes on selected species are included, either because their identification presented problems, or because their occurrence is noteworthy from an environmental point of view. Reliance for the identifi-

cations below has been placed on the Catalogue of Foraminifera (Ellis and Messina 1940 *et seq.*).

Suborder TEXTULARIINA

Ammobaculites barwonensis Collins
(Pl. 28, figs. 4, 5, 10-13)

DESCRIPTION: The specimens are moderately large (1-1.2 mm in length). The wall is finely agglutinated and fairly smoothly finished. The initial part is close coiled and slightly compressed, with about 5 chambers visible. This is usually the widest part of the test. The uncoiled part of the specimen is variable in shape and number of chambers. The majority of specimens have approximately five chambers, considerably wider than high. They vary from cylindrical to compressed in shape. The aperture is large and circular to elliptical in shape. A minority of specimens have a tendency to become strongly compressed and flabelliform. This may affect all the chambers in the uncoiled portion, or only the latest chambers. In flabelliform specimens the width of the latest chambers often exceeds that of the initial coil. The aperture in such specimens becomes an elongated slit. Up to 10 chambers are present in the uncoiled portion of flabelliform specimens. Continuous variation exists between the typical and flabelliform specimens.

REMARKS: This species was described (Collins 1974) from specimens collected on the bank of the Barwon River. Since Collins's small number of specimens do not show the considerable variability of the species, especially the flabelliform character of some specimens, description of the species as developed in the Gippsland Lakes is provided.

The species is much larger and more variable in morphology than the Recent species *Ammobaculites exiguus* Cushman and Bronnimann which is not compressed, and has mostly indistinct sutures. Most specimens of *A. barwonensis* have at least part of their test slightly compressed, and many specimens are markedly compressed while the sutures are always distinct. This species differs from *Ammobaculites agglutinans* (d'Orbigny) which also occurs in the Gippsland faunas (Pl. 28, fig. 9), in being larger, in having a much more involute initial coil, in the compression of the test, and in the tendency to become flabelliform in shape.

Trochamminita irregularis Cushman and Bronnimann
(Pl. 29, figs. 5, 6, 10, 14)

REMARKS: The small (?immature) specimens resemble *Jadammina macrescens* (Brady), but intermediate sized specimens begin to develop the irregular terminal chambers of *Trochamminita irregularis*, so that the entire population is referred to the latter species.

Martinotiella cf. **communis** (d'Orbigny)
(Pl. 29, figs. 4, 9)

Clavulina communis (d'Orbigny, 1826); Ellis & Messina, Catalogue of Foraminifera.
Martinotiella communis (d'Orbigny); Loeblich & Tappan, 1964: C282, fig. 188, 10a-b.

REMARKS. The specimens found have a short trochospiral/triserial stage followed by only two biserial chambers, and usually five uniserial chambers. Occasional specimens have up to eleven uniserial chambers. The chambers are wider than high, and sutures are well defined. The specimens appear to be referable to *Martinotiella communis* as figured by Brady (Barker, 1960, Pl. 48, Fig. 3, 6-8). Collins (1974) has recorded *Martinotiella primaeva* (Cushman) as very rare in Port Phillip Bay, but not *M. communis*. However, specimens referred to *M. communis* by Taylor from offshore Gippsland waters are more robust and have a smoother, more rounded initial end. In Bass Strait waters off Gippsland, Taylor and Mee (pers. comm.) found *M. communis* only below 220 m, with a peak of abundance at 750 m. The identification of the Gippsland Lakes form as '*M* cf. *communis*' is therefore tentative.

Suborder ROTALIINA

Elphidium articulatum (d'Orbigny)
(Pl. 28, figs. 6, 7)

Elphidium articulatum (d'Orbigny); Murray, 1971: 153, Pl. 63.

Cribroelphidium poeyanum (d'Orbigny)
(Pl. 28, fig. 3, 8)

Elphidiononion poeyanum (d'Orbigny); Barker, 1960: Pl. 109, Fig. 22a.
Cribroelphidium poeyanum (d'Orbigny); Loeblich & Tappan, 1964: C635-6, Fig. 508, nos 3, 4.

REMARKS: A small number of specimens intermediate in morphology between *Elphidium articulatum* and *Cribroelphidium poeyanum* are present in Fauna 7B developed in small pools at Bunga Head. The specimens are less compressed than *E. articulatum* and are less ornamented along the sutures. They differ from *C. poeyanum* in having less inflated chambers in the last whorl (see Pl. 28, fig. 8).

Ammonia aoteanus (Finlay)
(Pl. 27, figs. 5, 6; Pl. 29, figs. 1, 2)

Streblus aoteanus (Finlay, 1940: 461-462).
Ammonia aoteanus (Finlay); Hedley, Hurdle & Burnett, 1967: Pl. 11, Figs. 4A-C, Text-figs. 56-60.
Ammonia aoteanus (Finley); Collins, 1974; Pl. 3, Figs. 30a-c.

REMARKS: This is the most prolific and widespread species in the Gippsland Lakes, stretching from Lake Wellington to Lakes Entrance. It reaches its acme in Fauna 2. There is a great range in size, from large (1.0 mm diameter) specimens in Fauna 2 to much smaller adults in Fauna 5B. A full range of sizes occurs in each of Faunas 1 to 4. Specimens from arenaceous dominated faunas (5B, 5C, etc.) and from samples with low pH values are smaller, and much thinner walled than those in Fauna 2. This trend towards thinner walls with increasing distance from the sea reaches its maximum in Lake Wellington (Fauna 5B), where many specimens of *Ammonia aoteanus* have undergone partial or complete dissolution of the calcareous wall. The latter specimens survive in the Recent sediments in the form of fragile brown organic specimen linings (see Pl. 29, fig. 2). Low pH values (below 6.5) are presumed responsible for this dissolution.

Ammonia aoteanus was described from New Zealand by Finlay, who apparently differentiated it from *A. beccarii* mainly on the narrower less pustulose umbilicus and the complete lack of nodular ornament along the sutures. Hed-

ley, Hurdle and Burdett (1967) say of *A. aoteanus* that 'the umbilical fissures are bordered by clear shell material but no beads or bosses are present along the sutures. When present, the umbilical plug may be distinct or pustulate in appearance'. Collins (1974, Pl. 3, Fig. 30) has figured a specimen of *A. aoteanus* which is fairly strongly pustulate in the umbilical area, but with unornamented umbilical sutures. Gippsland Lakes specimens generally correspond to the description of *A. aoteanus*. However, there is great variability in the form of chamber flaps and pillars developed on the ventral side. Some large specimens entirely lack pillars in the umbilical region, while in others a moderate number of these are developed. Some specimens have numerous small nodules developed in the umbilical fissures between the chambers, and on the umbilical tips of the chambers themselves. These forms appear to be transitional to true *A. beccarii*. Specimens belonging to *A. beccarii* are common in Recent material from Peel Inlet, southwestern Australia in the author's collection. Here, the nodular, sutured *beccarii* form is almost as common as the unornamented *aoteanus* form. Similar specimens were described by Quilty (1977) from Hardy Inlet (extreme S.W. Australia). The specimens referred to *Streblus beccarii* by McKenzie (1962) from the nearby Oyster Harbour were apparently the same form. These Southwestern Australian estuarine faunas are characterized by warm temperate species (especially those of McKenzie) whilst the Gippsland Lakes faunas are typically cold temperate. It is postulated here that *A. aoteanus* is a cool temperature water morphotype of *A. beccarii*.

Virgulinella fragilis Grindell and Collen, 1976
(Pl. 27, fig. 9)

Virgulinella fragilis Grindell & Collen, 1976; Pl. 1.

REMARKS: This species is rare in Fauna 2. Recently described from New Zealand, this seems to be its first record from Australian waters.

ACKNOWLEDGMENTS

Samples were prepared and examined in the geological laboratories of Shell Development (Aust.) Pty. Ltd. in Melbourne and Woodside Petroleum Development Pty. Ltd. (formerly BOCAL Pty. Ltd.) in Perth. I am indebted to both companies for the use of facilities, and to Woodside Petroleum for the drafting of the figures. The Victorian Department of Minerals and Energy, Chemical Branch, kindly provided salinity measurements on water samples. The Victorian State Rivers and Water Supply Commission made available salinity data from their sampling stations in the Gippsland Lakes. I am indebted to Jocelyn Terry-Evans for the compilation of all relevant data from this source. Thanks are also due to the Geology Department of the University of Melbourne and to West Australian Petroleum Pty. Ltd. for supplying scanning electron microscope photographs of the foraminifera. David J. Taylor gave invaluable guidance at all stages of the project, and critically reviewed the paper. Robin Winton and Gaye Schillerman typed the manuscript. Above all I am grateful to my husband, W. J. Kunert, without whose practical help and constant encouragement the study could not have been carried out.

REFERENCES

ALBANI, A. D., 1968a. *Recent Foraminiferida of the central coast of New South Wales*. AMSA Handbook, No. 1, Australian Marine Sciences Association, Sydney.

———, 1968b. Recent Foraminiferida from Port Hacking, New South Wales. *Contr. Cushman Fdn. foramin. Res.* 19: 85-119.

———, 1970. A foraminiferal fauna from the eastern continental shelf of Australia. *Contr. Cushman Fdn. foramin. Res.* 21: 71-77.

ALBANI, A. D. & JOHNSON, K. R., 1975. Resolution of foraminiferal biotopes in Broken Bay, N.S.W. *J. Geol. Soc. Aust.* 22: 435-446.

BARKER, R. W., 1960. Taxonomic notes on the species figured by H. B. Brady in his report on the foraminifera dredged by H.M.S. Challenger during the years 1873-1876. *Spec. Publs. Soc. Econ. Paleont. Miner. Tulsa* 9.

BIRD, E. C. F., 1965. A geomorphological study of the Gippsland Lakes. *Dep. Geog. Pub. Aust. Nat. Univ.* G/1.

CARTER, A. N., 1964. Tertiary Foraminifera from Gippsland, Victoria, and their stratigraphical significance. *Mem. geol. Surv. Vict.* 23.

COLLINS, A. C., 1953. Pleistocene Foraminifera from Port Fairy, Western Victoria. *Mem. natn. Mus. Melb.* 18: 93-105.

———, 1958. Foraminifera. *Scient. Rep. Gt. Barrier Reef Exped.* 6: 335-437.

———, 1974. Port Phillip Survey 1957-63 Foraminiferida. *Mem. natn. Mus. Melb.* 35: 1-61.

CUSHMAN, J. A. & BRONNIMANN, P., 1948. Some new genera and species of Foraminifera from brackish water of Trinidad. *Contr. Cushman Lab. foramin. Res.* 24: 15-21.

ELLIS, B. F. & MESSINA, A. R., 1940 *et seq. Catalogue of Foraminifera*. Special Publication, American Museum of Natural History, New York.

FINLAY, H. J., 1940. New Zealand Foraminifera: key species in stratigraphy, No. 4. *Trans. R. Soc. N.Z.* 69: 448-472.

GRINDEL, D. A. & COLLEN, J. D., 1976. *Virgulinella fragilis* n.sp. (Foraminiferida) from Wellington Harbour, New Zealand. *Revista esp. Micropaleont.* 8: 273-278.

HEDLEY, R. H. HURDLE, C. M. & BURDETT, I. D. J., 1967. The marine fauna of New Zealand: intertidal foraminifera of the *Corallina officinalis* Zone. *Bull. N.Z. Dep. scient. ind. Res.* 180.

LE CALVEZ, Y., 1974. *Revision des Foraminifères de la collection d'Orbigny. 1, Foraminifères des Iles Canaries. Cahiers de Micropaléontologie* 2. Centre National de la Recherche Scientifique Paris.

LEVY, A., MATHIEU, R., POIGNANT, A., ROSSET-MOULINIER, M. & ROUVILLOIS, A., 1947. Les représentants des Ammodiscacea, Lituolacea, Nodosariacea, Buliminacea (Foraminifères) dans les sables des plages de Dunkerque. Remarques sur les espèces signalées par O. Terquem. *Revue Micropaléont.* 17: 127-133.

——, ——, ——, —— & ——, 1975. Sur quelques foraminiferes actuels des plages du Dunkerque et des environs: Néotypes et espece nouvelle. *Ibid.* 17: 171-181.

LOEBLICH, A. R. Jnr. & TAPPAN, H., 1964. *Treatise on Invertebrate Paleontology, Part C, Protista 2*. Geological Society of America & University of Kansas Press, Lawrence.

MCKENZIE, K. G., 1962. A record of Foraminifera from Oyster Harbour, near Albany, Western Australia. *J. Proc. R. Soc. West. Aust.* 45: 117-132.

MURRAY, J. W., 1971. *An atlas of British Recent foraminiferids*. Heinemann, London.

——, 1973. *Distribution and ecology of living benthic foraminiferids*. Heinemann, London.

PARR, W. J., 1939. Foraminifera of the Pliocene of South-Eastern Australia. *Min. geol. J.* 1(4): 65-71.

——, 1945. Recent Foraminifera from Barwon Heads, Victoria. *Proc. R. Soc. Vict.* 56: 189-218.

PARR, W. J. & COLLINS, A. C., 1930. Notes on Australian and New Zealand Foraminifera. No. 1 — The species of *Patellina* and *Patellinella*, with a description of a new genus, *Annulopatellina*. *Ibid.* 43: 89-95.

PHLEGER, F. B., 1960. *Ecology and distribution of Recent Foraminifera*. Johns Hopkins Press, Baltimore.

QUILTY, P. G., 1977. Foraminifera of Hardy Inlet, south-western Australia. *J. Proc. R. Soc. West. Aust.* 59: 79-90.

SEIGLIE, G. A., 1975. Foraminifers of Guayanilla Bay and their use as environmental indicators. *Revista esp. Micropaleont.* 7: 453-487.

SIEBOLD, I., 1975. Benthonic Foraminifera from the coast and lagoon of Cochin (South India). *Ibid.* 7: 175-213.

SLITER, W. V., 1970. Inner-neritic Bolivinitidae from the eastern Pacific margin. *Micropaleontology* 16: 155-174.

TODD, R., 1965. The Foraminifera of the tropical Pacific collections of the 'Albatross', 1899-1900. Pt. 4, Rotaliform families and planktonic families. *Bull. U.S. natn. Mus.* 161.

Description of Plates 26-29

Plate 26

Fauna 1: Semi-Marine

1. *Quinqueloculina seminulum* (Linné); Sample 144 X110. 2. *Quinqueloculina tropicalis* Cushman; Sample 144 × 132.3. *Miliolinella subrotunda* (Montagu); Sample 144 × 190. 4. *Quinqueloculina* cf. *ferussacii* d'Orbigny; Sample 128 × 83. 5. *Rosalina* sp.; Sample 143 × 215.6. *Bolivina variabilis* (Williamson); Sample 18 X232. 7. *Discorbinella subbertheloti* (Cushman); Sample 143 X185. 8. *Pileolina patelliformis* (Brady); Sample 143 X237. 9. *Trochammina rotaliformis* Heron-Allen and Earland; Sample 242 X118. 10. *Elphidium advena* (Cushman); Sample 144 X145. 11. *Elphidium macellum* (Fichtel and Moll); Sample 142 × 94.

Plate 27

Fauna 1 (continued) and Faunas 2-3; Central Lakes

1. *Bolivina pseudoplicata* Heron-Allen and Earland; (Faunas 1-2); Sample 128 X200. 2. *Bolivina striatula* Cushman (Faunas 1-2); Sample 18 × 174.3. *Bulimina marginata* d'Orbigny (Faunas 1-2); Sample 128 × 132.4. *Textularia* sp. (Faunas 1-3); Sample 64 × 232. 5, 6. *Ammonia aoteanus* (Finlay) (all Faunas) opposite sides of different specimens; Sample 126 X91. 7, 10. *Eggerella advena* (Cushman) (most Faunas); 7: Sample 126 X124; 10: Sample 126 X83. 8. *Bulimina gibba* Fornasini (Faunas 1-2); Sample 19 X116. 9. *Virgulinella gracilis* Grindell and Collen (Faunas 2-3); Sample 55 X141. 11, 12. *Nonion depressulum* (Walker and Jacob) (all Faunas, typical of Fauna 3); 11: Sample 173 X75; 12: Sample 173 X83.

Plate 28

Fauna 4: Central Lakes

1, 2. *Elphidium oceanensis* (d'Orbigny) 1: Sample 113 detail, X348; 2: Sample 113 X108.

Faunas 7B, 7C: Peripheral Lakes

3, 8. *Cribroelphidium poeyanum* (d'Orbigny) (all Faunas, but typical of 7B, 7C) 3: Sample 30 X166; 8: Sample 128 X207. 6. *Elphidium articulatum* (d'Orbigny) (several Faunas, but typical of 7B, 7C); Sample 322 X149. 7. *Elphidium articulatum* transitional to *Cribroelphidium poeyanum* (compare with figure 8); (typical of Fauna 7B); Sample 322 X100.

Fauna 7A: Peripheral Lakes: Lake Bunga

4, 5, 10-13. *Ammobaculites barwonensis* (several Faunas, but typical of 7A). 4: Side view of specimen with elongated aperture; Sample 30 X91. 5: Typical specimen; Sample 11 X64. 10: Fairly common form, with eight chambers in uniserial portion of test; Sample 11 X58. 11: Large flabelliform specimen. All gradations between fig. 10 & 11 occur. Sample 30 X58. 12: Specimen with slightly compressed early uniserial chambers, becoming rounded in profile in final chamber; Sample 102 X100. 13: Detail of aperture of figure 12 X310. 9. *Ammobaculites agglutinans* (d'Orbigny) (several Faunas); Sample 83 X103.

Plate 29

Faunas 5B, 5C: Inner Lakes — Lake Wellington and Jones Bay

1. *Ammonia aoteanus* (Finlay) Spiral view of partially decalcified specimen, typical of Lake Wellington Faunas (5B); Sample 197 X240. 2. *Ammonia aoteanus* (Finlay) Umbilical view of wholly decalcified specimen, showing organic inner lining of the chambers. Lower part of the specimen is obscured by a layer of glue. Sample 232 X198. 3. *Miliammina fusca* (Brady); Sample 226 X75. 4, 9. *Martinotiella* cf. *communis* (d'Orbigny) 4: Sample 30 × 121. 9: Sample 197 × 108. 7. *Reophax barwonensis* Collins 7: Typical specimen, with bulbous initial chamber Sample 11 × 89. 15. Bryozoan Sample 30 × 10.

Fauna 5A: Inner Lakes

5, 6, 10, 14. *Trochamminita irregularis* Cushman and Brönnimann 5: Large specimen with multiple apertures; Sample 196 X66. 6: Large specimen with irregular coiling; Sample 232 X75. 10: Typical specimen with streptospiral coiling; Sample 196 X75. 14: Side view; Sample 196 X55. 8. *Reophax barwonensis* Collins 8: Form with test built of large sand grains and diatoms; Sample 196 X58. 11. *Miliammina fusca* (Brady). Specimen with embracing chambers, slightly longer than half the whorl in length, typical of Fauna 5A; Sample 196 X108.

Fauna 6A: High Energy Channels

12, 13. *Ammotium salsum* (Cushman and Brönnimann) (many Faunas, but common in 6A) 12: Sample 186 X83. 13: Sample 186 X70.

PLATE 26

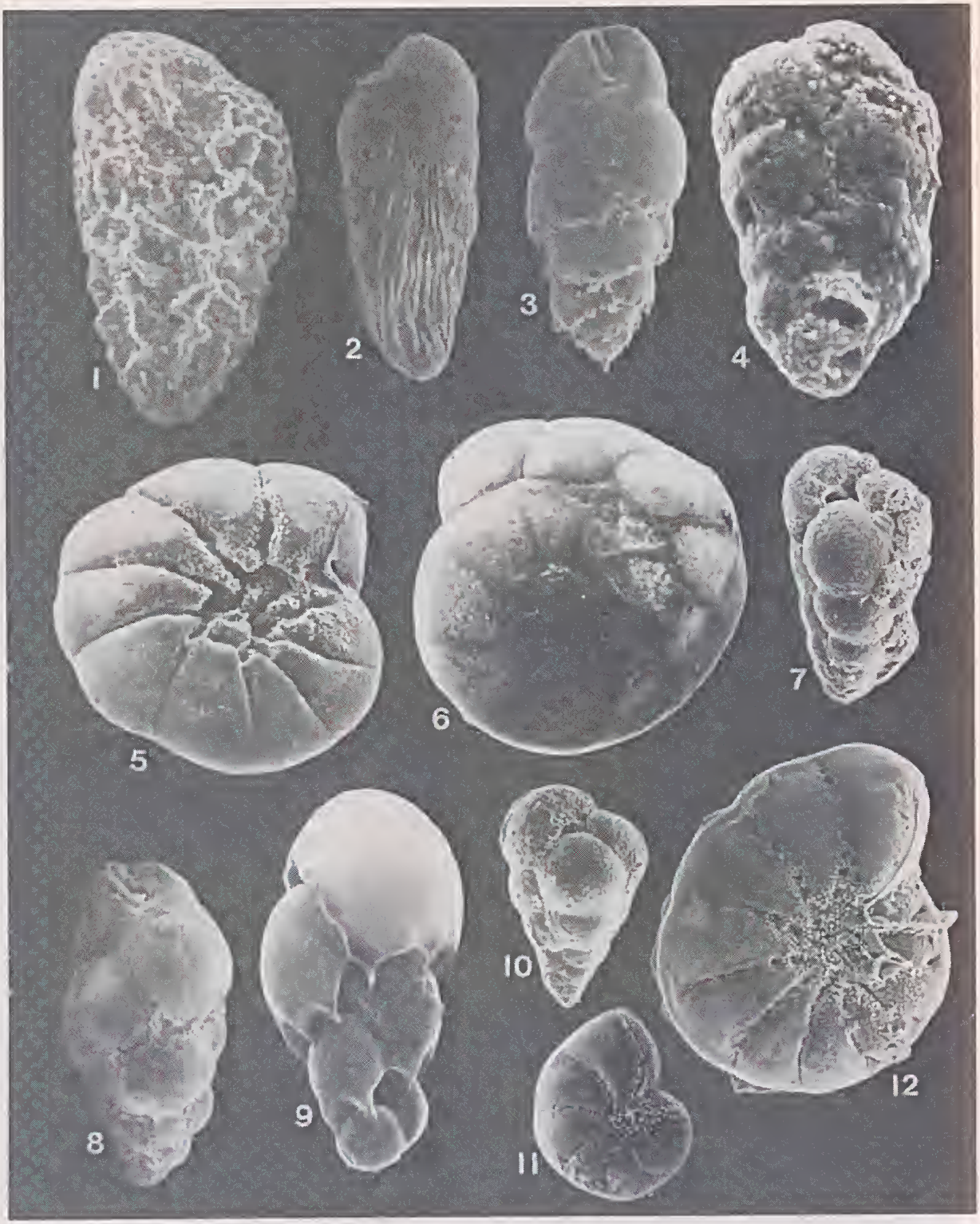


PLATE 27

PLATE 28

PLATE 29